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Published in:
World Renewable Energy Congress IX, Florence, Book of Abstracts

Publication date:
2006

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Sørensen, B. (2006). Efficiency or renewable energy - which comes first? In *World Renewable Energy Congress IX, Florence, Book of Abstracts* (pp. 11). WREN.

Efficiency or renewable energy – which comes first?

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Abstract

Most national energy policies place considerably more emphasis on the development of new energy supply technologies than on improvements in the efficiency with which energy is used during conversion chains all the way to the end user transforming energy into a desired product or service. Maybe the supply side is seen as more publicity-suited than the demand side developments. The present study uses a number of case studies to exemplify the relative costs and gains pertaining to policy-favoured new renewable energy and related supply technologies, as compared to the costs and gains of performing efficiency improvements in areas such as passenger or freight transportation. Furthermore, the study highlights the time horizons characterising the competing supply and demand side technologies, and it is suggested, that few of the supply side options have time horizons as short as some of the demand side efforts that may be based on already proven technologies.

Keywords: *energy efficiency, supply-side technology, demand-side technology. renewable energy, hydrogen, vehicles.*

1. Introduction

Three main examples are discussed in this paper: passenger transportation, equipment using electric energy, and heating of buildings. In all cases, an effort to find more efficient ways of satisfying the end-users demand for energy-service has been ongoing, along with efforts to develop new sources of the various energy forms, that avoid issues of pollution, climate impacts and resource availability. The paper intends to summarise the status of these supply- and demand-side measures, in order to assess their technical and economic status as well as market positions. For the solutions still under development the analysis may indicate, whether or not the financial R&D support is well spent by its current distribution over the supply and demand sides.

2. Road transportation

The prospect of oil supply problems due to limited resources and political instability of the supply countries with largest reserves has spurred interest in substitution technologies, as well as in stretching the remaining oil as far as possible. In the second category are vehicle efficiency improvements, while the first category comprises development of bio-fuel and hydrogen/fuel cell vehicles. Table 1 summarises data on current technical readiness or estimated development time, on viability in terms of equipment lifetime and maintenance requirements, and on current direct and indirect (life-cycle) costs and estimated cost evolution trends.

Table 1. Comparison of "time-to-readiness or viability" for road vehicles using hydrogen/fuel cell and oil/high-efficiency technologies [1,4].

	Technical readiness	***Market readiness***	***Cost viability***
Efficient diesel cars	0 y	0 y	0-5 y
Fuel cell hydrogen cars	5-15 y	10-? y	20-? y

The efficient passenger car is having a common-rail diesel engine with efficiency above 50%, using diesel-oil as fuel It is equipped with efficiency measures such as brake-energy recovery and engine shut-off during idling, in addition to having low air and rolling resistance The materials used are light, yet capable of sustaining high security requirements (e.g. in crash tests), the bare mass of the 4- to 5-seat car is around 800 kg, and the carrying capacity (fuel, people and cargo) some 350 kg. Based on standard driving cycles, the average fuel-to-wheel efficiency of such cars are around 0.26, corresponding to a fuel use near 1 MJ/km or about 30 km/litre of fuel. Such vehicles became commercially available around 1998 and have increasingly appeared on the market. Compared to the first such vehicle (VW Lupo 3L), recent examples show efficiencies some 10% poorer, but with a market price that can no longer be distinguished from that of less efficient cars, in contrast to that of the Lupo, which was some 10% above similar cars with low efficiency (the Lupo is no longer in production). Similar remarks can be made for freight transportation [1].

In other words, the efficient passenger car is a proven concept, available on the market and at costs that no longer exceeds those of less efficient cars. The reason that market shares are still modest is that promotion of cars is still done on the basis of other features than energy efficiency. If all cars and other vehicles were of the efficient type described above, the global fuel use would be nearly a third of the present one, allowing growth in the new markets in Asia and at the same time less pressure on resources (for example, the USA would become self-sufficient for oil in the transportation sector from its indigenous oil production, at the level of current extraction).

For the replacement of oil-derived fuels by hydrogen used in fuel cells, there are substantial R&D programs all over the world. Current demonstration prototype fuel cells have low durability (under two years) and high cost. Technical goals such as 5 years durability (which for passenger cars corresponds to 5000 hours) are considered within reach over the next 5-10 years. However, cost reductions are likely to take longer, and since the average life of a car is currently some 15 years and increasing, this would mean several replacements of fuel cells in each vehicle, making a realistic cost goal for the fuel cell propulsion system (including electric motor and hydrogen storage containers, which are supposed to have longer lifetime than the fuel cell itself) at least three times lower than for present systems. It is not possible at present to say, if such a goal is at all attainable. From the market point of view, additional requirements include establishment of filling station infrastructure, as well as the production of hydrogen at a reasonable cost. The basis would initially be non-oil fossil fuels and later renewable energy, such as wind power (through electrolysis or reverse fuel cell operation).

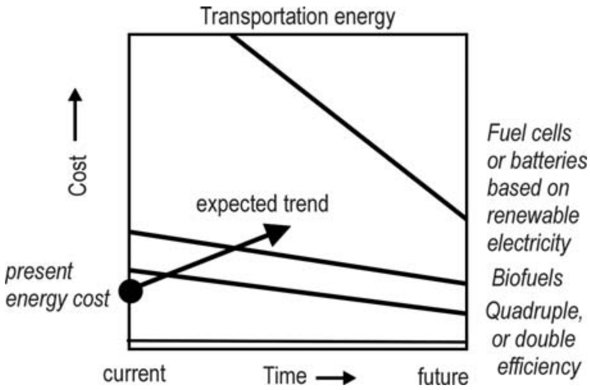

Figure 1. Comparison for the transportation sector of current cost trends with those of efficiency measures and introduction of biofuels or hydrogen (with advanced-battery charging as an alternative) derived from renewable electricity.

The expectation is, that the best strategy for introducing hydrogen in the transportation sector is to start with hybrid vehicles [2,3]. These have lower fuel cell rating (and thus cost) and a traction battery that is rated at a far lower value than the one required for a purely electric vehicle (due to driving range goals of over 600 km for general passenger cars). For comparison, some of the efficient diesel cars already on the market have a range of about 1000 km on a full tank.

The transportation sector is considered a critical energy supply market, because of the difficulty in rapid introduction of substitution technologies (as compared e.g. with the stationary electricity-use sector). A possible exception is liquid biofuels. The analysis above supports this view and shows that transition time can be bought at near zero cost, if the full potential of energy efficient vehicles is brought onto the market by asserted policy action. This is illustrated in Figure 1.

3. Electrical equipment

The total number of electrical appliances and other equipment used in homes and workplaces is rapidly increasing. Home utility appliances, entertainment systems and computing facilities have in sequence had unprecedented growth periods. However, the total electricity demand is still growing less rapidly than the demand in the transportation sector. The reason for this is entirely the higher success of introducing efficiency measures for appliances using electric power. This materialised with household appliances after the 1973/4 energy supply crisis, with average energy requirements for the same-volume refrigerator, freezer, clothes or dishwashing machines dropping by a factor of more than 4 between 1970 and 2005, at least in Europe. A similar development has taken place for entertainment equipment, associated with technology change: A-type sound producing equipment always operating at maximum power has been replaced by flexible technology adapting energy use in correlation to the sound output, and CTR picture tube video displays are being replaced by flat-screen technologies using an order of magnitude less energy. For computers and associated peripherals, the damage caused by excess heat release has made manufacturers implement high energy efficiency without any other incentive, and despite orders of magnitude increase in computing power, the overall energy use has gone down, although mostly compensated by growth in numbers of computers and peripherals installed by the same user [5].

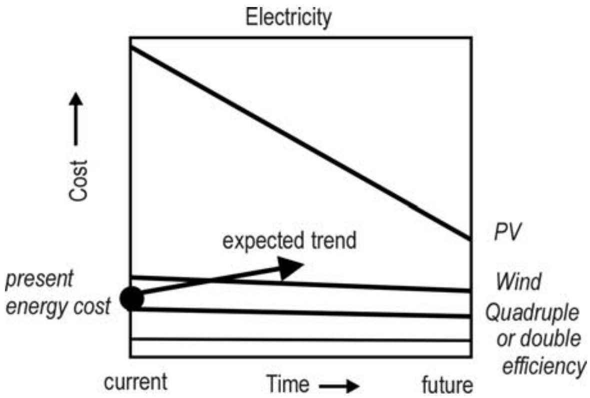

Figure 2. Comparison for the sector of electricity use of current cost trends with those of efficiency measures and introduction of electricity from renewable energy sources.

The ongoing efficiency improvement of end-user electric equipment has saved this sector from a major increase in supply requirements. Still, there are further efficiency increasing measures that could be taken, some with known technology and modest cost, others requiring new developments and possibly a higher cost. The viability of this depends on the cost of expanding supply, which is expected to entail rising costs, either for natural gas or coal-fired power plants with CO_2 removal, or for production based on renewable energy, where wind energy in many locations is the lowest-cost option, followed by biomass, and with photovoltaic being the most expensive. For biomass it is important to realise, that simple combustion is not a lasting option, due to high emissions even with advanced burning techniques, and due to the likely competition with biofuel use in the transportation sector, which is capable of paying considerably more per unit of energy.

4. Low-temperature heat

Low-temperature heat is used for space heating in buildings, for hot water service supply and for certain types of process heat in the service and industry sectors. The efficiency of space heating depends on the quality of the building in terms of heat losses, e.g. through insulation or by air exchange. Current average-building energy performance is typically half as good as that of new buildings (due to energy requirements increasingly becoming part of building codes, at least in Europe), but four times lower than the best of the new houses on the market today. Improving the performance of existing buildings may be achieved by adding insulation and better controlling air infiltration, but the nature of materials and methods used in existing houses often makes retrofitting to the best standard difficult. Compounded by the very long average lifetime of buildings (of the order of 100 years in Europe, somewhat less in other parts of the world), this implies that end-use efficiency improvements beyond a certain level are difficult to achieve as quickly in the building sector as in most other sectors.

Table2. Comparison of time-to-readiness and payback-time for building requirements of low-temperature heat as satisfied by selected supply or demand side measures [5].

	Technical readiness	***Market readiness***	***Cost payback***
New, efficient building	0 y	0 y	5-10 y
Retrofitting for efficiency	0 y	0 y	10-30 y
Solar heat w/store	0 y	0-5 y	20-60 y
Heat pump	0 y	0-5 y	10-30 y

On the supply side, building energy has traditionally been based on combustion of fuels or by district heating. Due to the poor environmental performance of small boilers and losses in transmission, this is not a sustainable solution, even if fuels would remain available. Future solutions comprise solar heat and electricity (e.g. from wind). Solar heat collectors with forced air or water flow delivering the heat are near viability in climates with sunny winters, provided that the houses in question already have a heat distribution system based on water or air. An amount of heat storage is required for a solar heat system. At high latitudes, the seasonal variation in solar radiation is anti-correlated with heat demand, and the solar solution including storage requirements becomes increasingly unrealistic, except for limited hot-water supply during summer periods.

The heat pump solution allows electricity-to-heat conversion to take place with use of environmental heat, such that the exergy balance is acceptable. In milder climates, the heat pump system may be able to supply sufficient heat when using environmental heat from the air or from waste-water, but in situations of more severe winters, this is often insufficient and environmental heat must be derived from frost-free soil (at a depth of typically 60-90 cm) or waterways. Constructing soil heat exchangers, e.g. by horizontal pipe injection, increases the cost of the system considerably. On the hot side, the heat pump may use water if a water distribution system is present in the building, and air if air-based distribution is feasible, e.g. in connection with an air conditioning system (as would be present in buildings already built or retrofitted to low air infiltration standards). Large heat pump systems may achieve a coefficient of performance (COP, i.e. the ratio of heat output to electricity input) near 4, but smaller systems rarely more than 3 [5].

5. Policy measures

Present markets do not generally work to promote the best solutions sketched here. In new markets such as the Chinese one, expansion in car sales is high in the most inefficient cars, often luxury cars built with no consideration of fuel efficiency whatsoever. Measures that would correct these market failures in dealing with oil supply problems could be either taxation or regulation. Imposing an efficiency-dependent tax on cars has been tried in Denmark, with a noticeable shift in purchasing choice entailed, and the higher fuel taxation in Europe than in the USA has caused the average vehicle efficiency ratio to match (with inverse proportionality) the fuel cost as seen by the customer. Regulatory measures would be similar to that of building codes, aimed to prevent construction of unsafe houses and houses with excessive energy requirements. Another positive side-effect would be that the more efficient cars somewhat ease city parking and reduce road congestion, although these effects are smaller that the effect of e.g. increasing seat occupancy.

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